

# **Femtosecond Laser Processing of Materials for Defense Applications**

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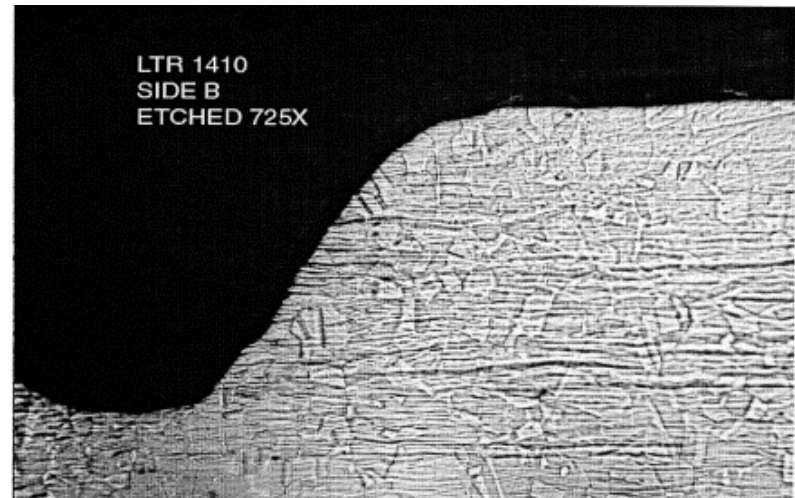
Our femtosecond laser safely cuts energetic materials and metals with surgical precision

Cuts cold and clean



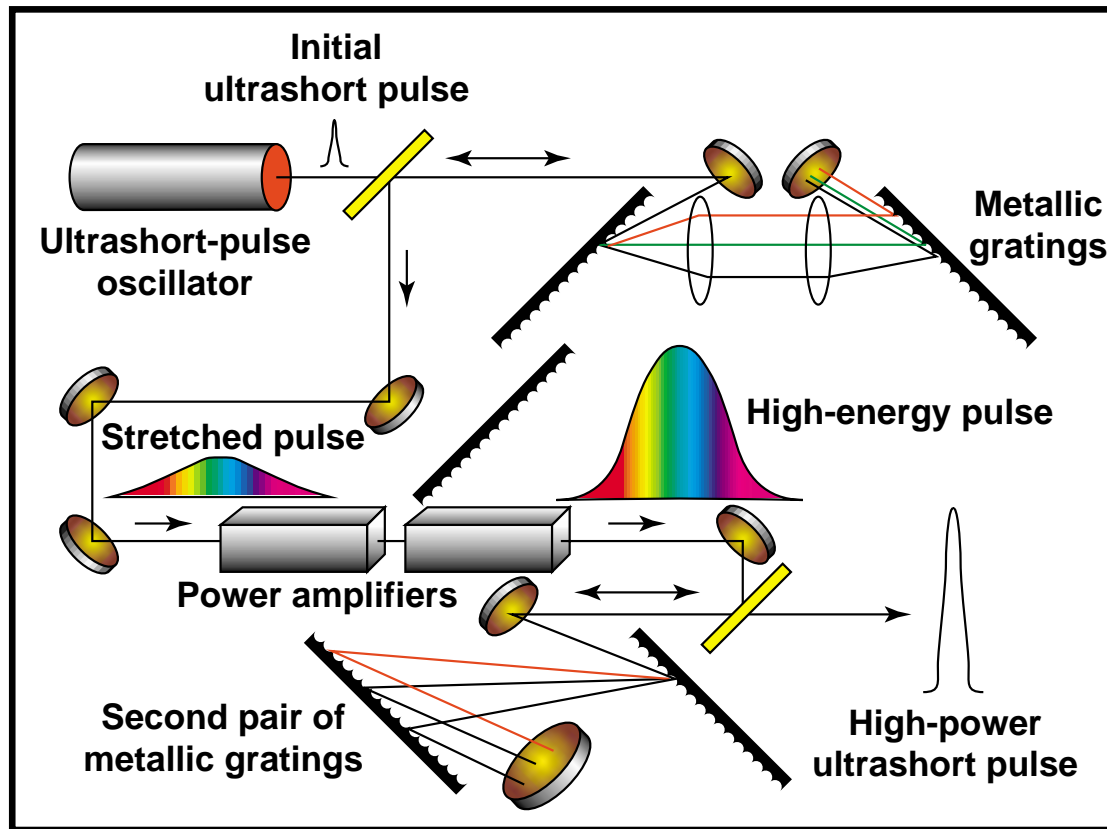
Cuts anything

Near-zero heat transfer



Minimal wastes

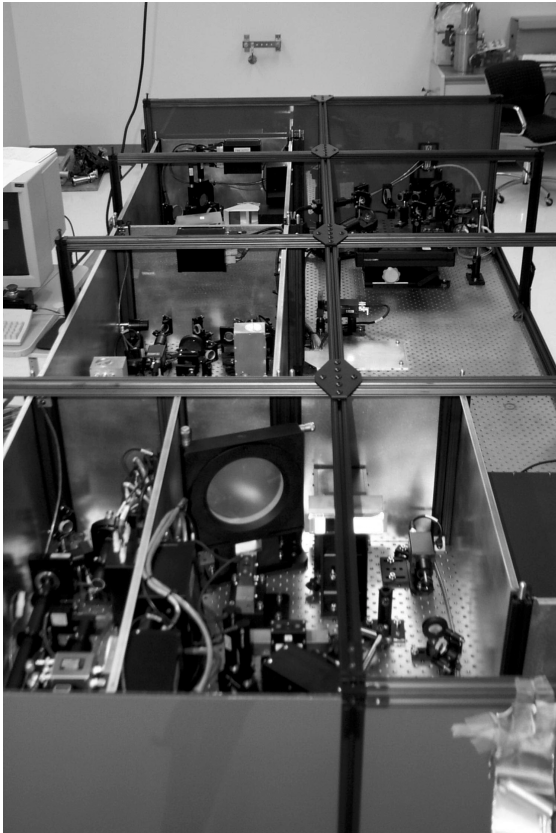
# How a femtosecond pulse laser works



- ¥ Pulse width: 150 fs
- ¥ Average power: up to 3 W
- ¥ Peak energy: 1 mJ/pulse
- ¥ Peak power: 40 GW
- ¥ Repetition rate: 3.5 kHz
- ¥ Beam Diameter: 13 mm
- ¥ Wavelength: 810 nm

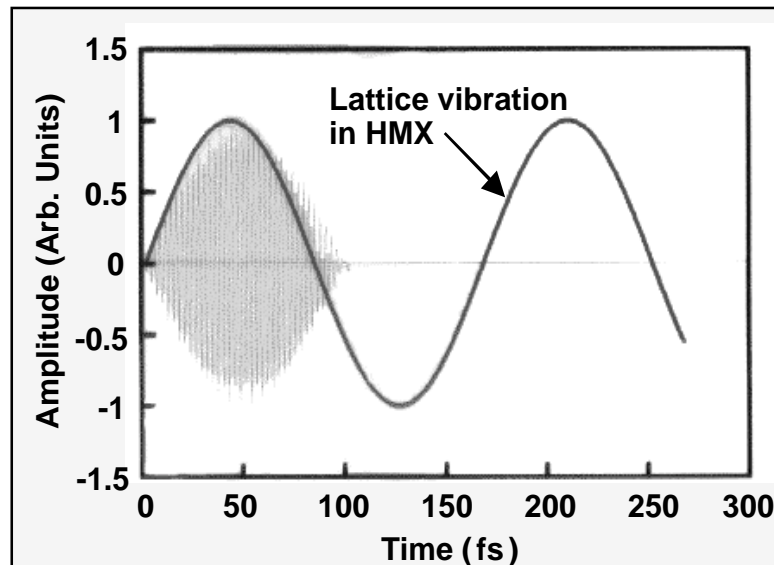
# The laser consists of several modules

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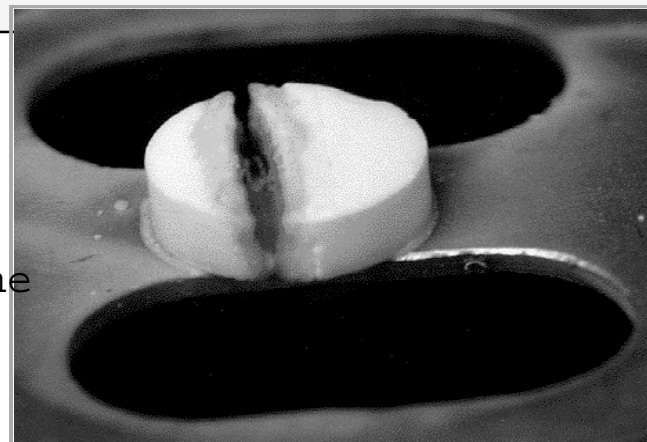
The laser is computer  
controlled  
with auto alignment system

# How can the laser cut HE without thermal transfer?



- ✖ Heat is transferred by lattice vibrations
- ✖ Energy absorption occurs on a time scale comparable to a single lattice vibration
- ✖ Subsequent hydro expansion and cooling is also too fast for heat transfer
- ✖ Shock wave is intense but too brief to cause significant reaction

Thermal transfer to the  
HE is evident with longer  
pulses (0.15)



# Laser Interaction with insulating material

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Long pulse - cw - 10 ps

## Avalanche ionization

Requires seed electron - threshold  
has large deviation

- ¥ Free electrons reach high density -
- ¥ Irreversible material breakdown occurs and ablation begins
- ¥ electrons absorb laser energy by collisions with ions and are heated to high temperature
- ¥ at the same time electrons transfer energy to the ions and lattice and the material is heated up
- ¥ the amount of heating during the laser pulse depends on the pulse duration and energy coupling coefficient
- ¥ absorbed energy leaves the laser focal volume via heat conduction.
- ¥ energy transfer from electrons to ions during laser-matter interaction is strong - large volume around the laser focus is melted and relatively small layer of material reaches vaporization temperature.

Short pulse -  $< 1$  ps

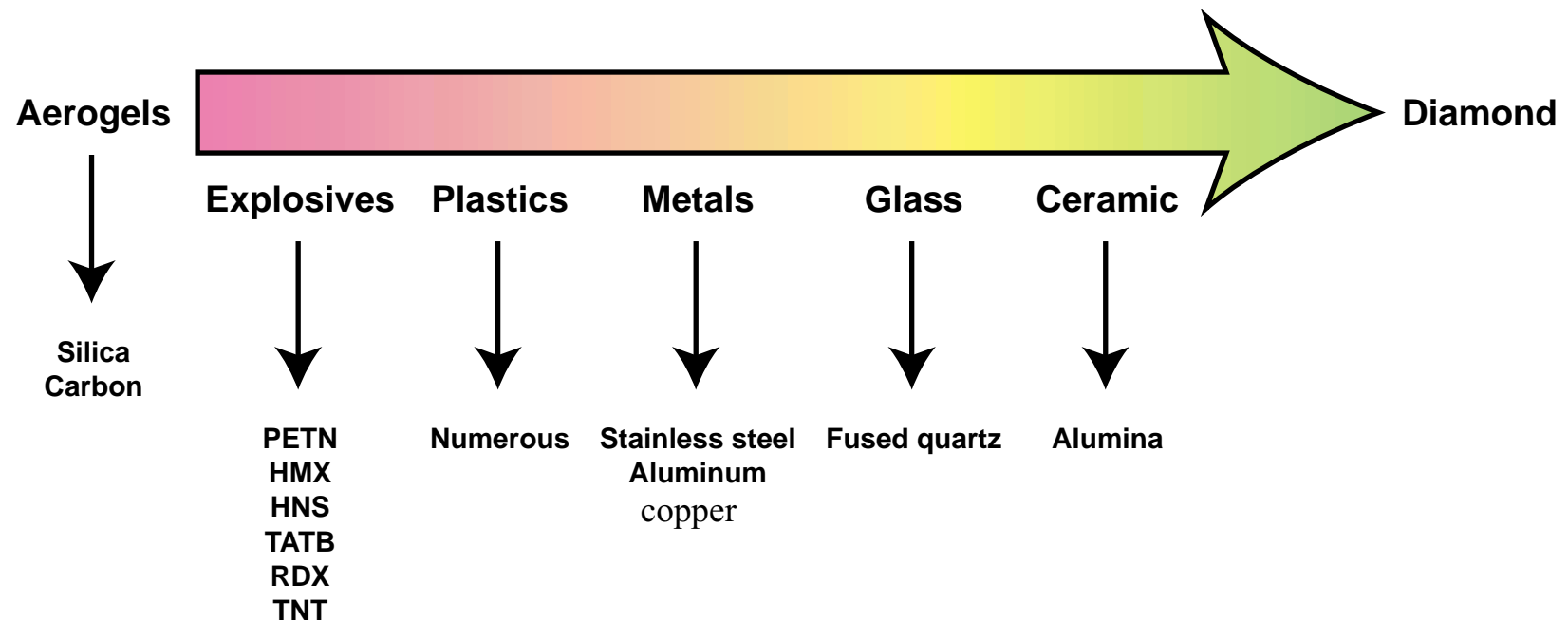
## Multiphoton ionization

Bound electrons absorb  $m$  photons simultaneously to become ionized

- ¥ interaction time is short
- ¥ electrons driven to much higher temperature and the ion or lattice temperature much lower
- ¥ subsequent electron-ion energy transfer takes place after the pulse is over and will heat ions to a much higher temperature than the long-pulse case
- ¥ A large fraction of the material in the interaction volume is vaporized, going through the melt phase very rapidly.
- ¥ The heat-affected volume due to conduction is much smaller and most of the energy is carried away by vaporization.

# Ultrashort laser pulses will cut any material

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# **Programmatic applications for fs lasers**

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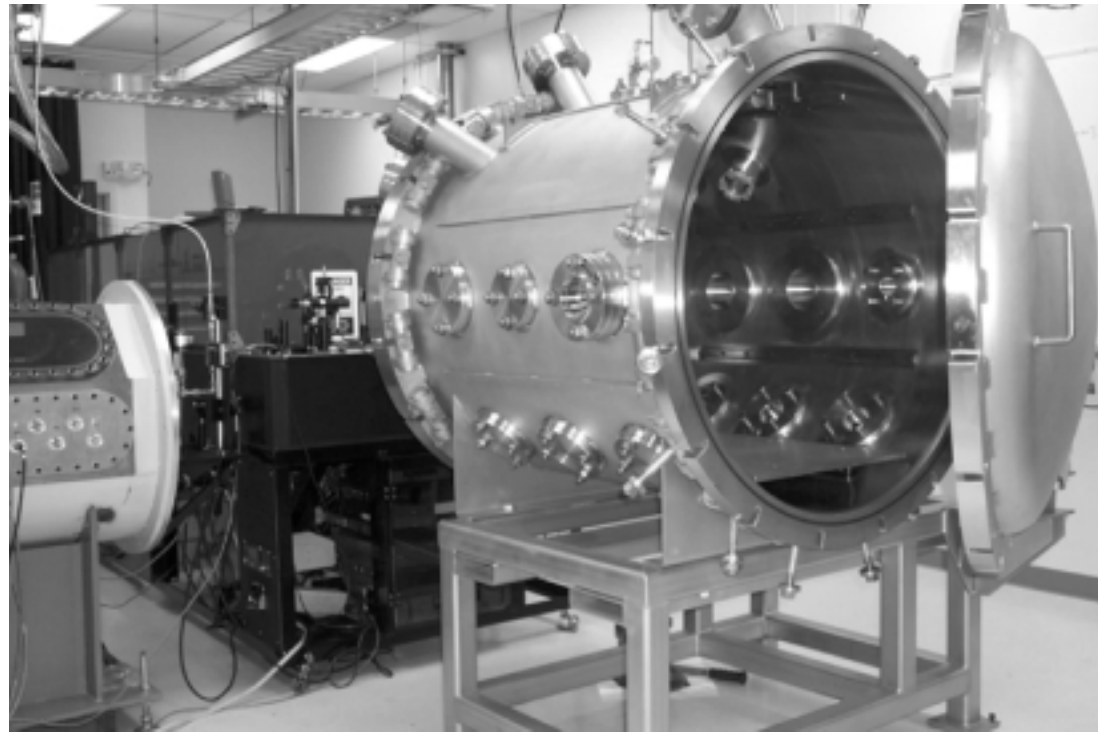
¥ **Energetic materials processing**

¥ **Scientific investigation**

¥ **Surveillance**

¥ **Micromachining**

¥ **Demilitarization**



**We have a 4-axis-motion positioning system**

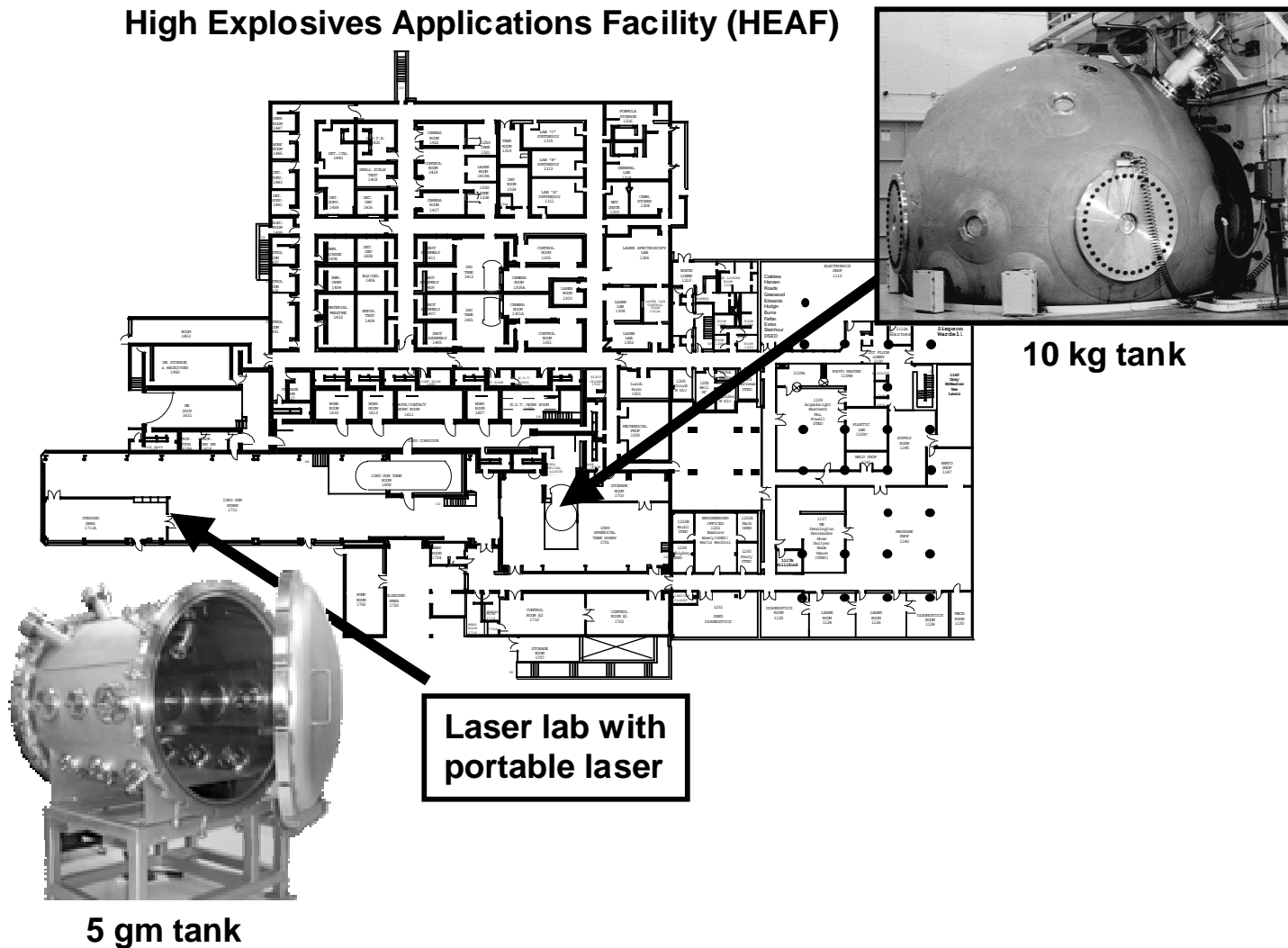
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**We have the flexibility to cut small or large explosive samples**



## High Explosives Applications Facility (HEAF)



**10 kg tank**

**Laser lab with  
portable laser**

**5 gm tank**

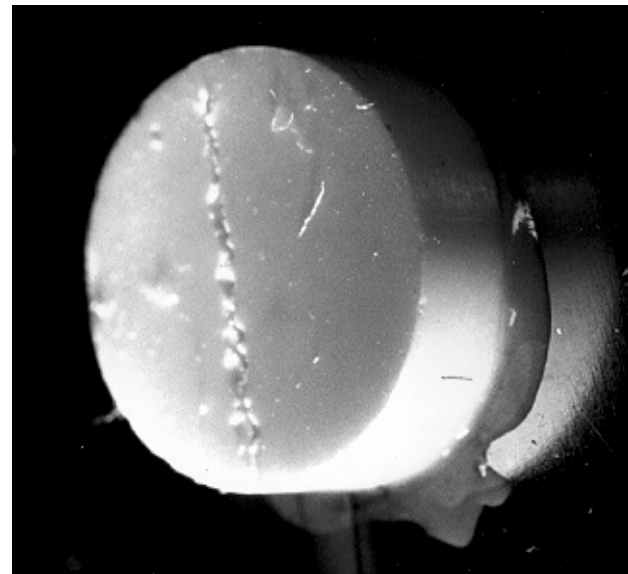
# Energetic materials processing

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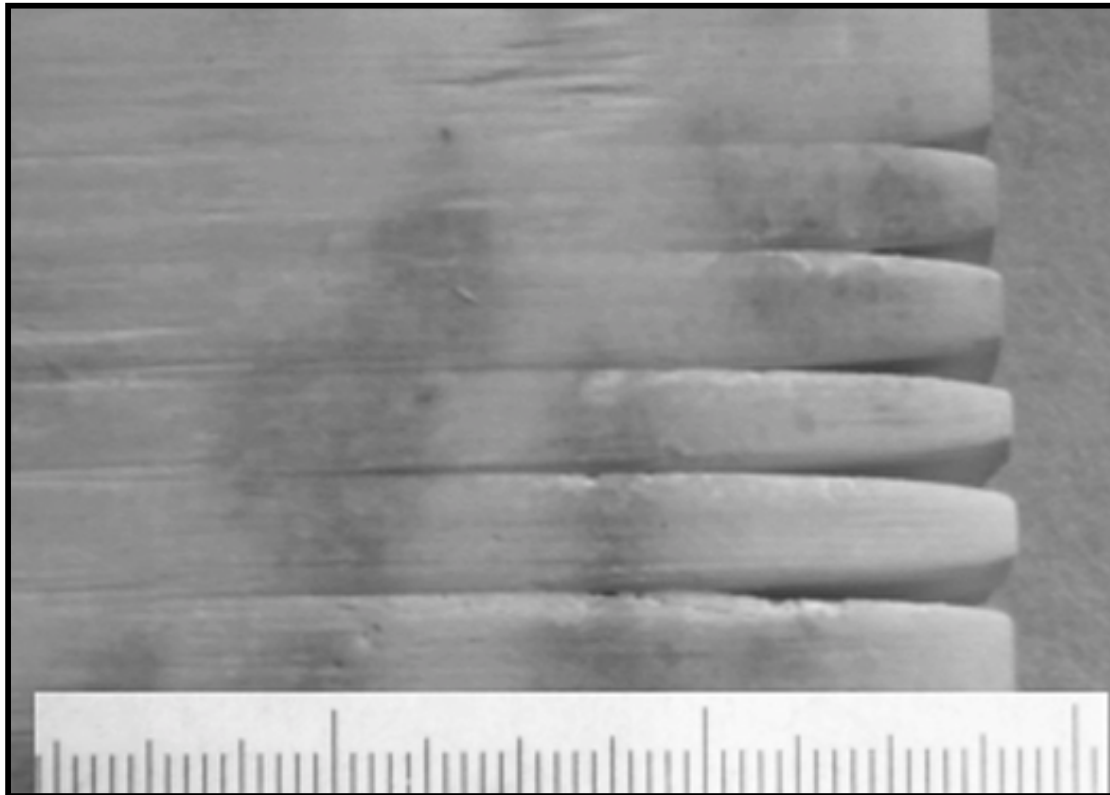
**We have demonstrated that we can cut and machine high explosives with a focused beam from a high-power, femtosecond laser with virtually no heat transfer to the explosive. This capability has interesting applications to the processing of energetic materials.**

- Precision machining of HE components**
- Elimination of HE waste and HE-contaminated waste**
- Reduction of pressing costs and achievement of greater pellet uniformity by machining booster and detonator pellets from a larger pressing**

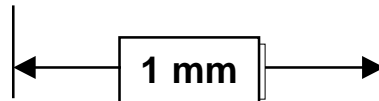


## The laser can make very fine cuts

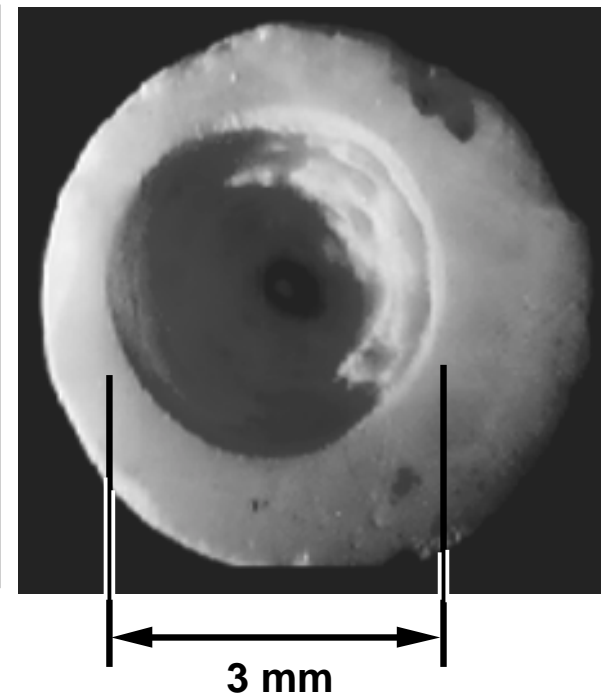
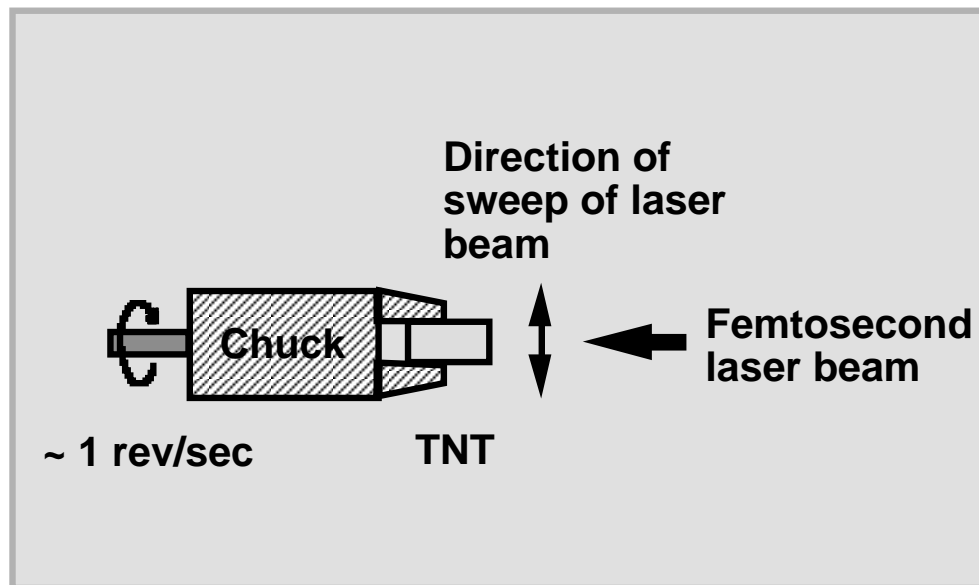
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Cuts are on  
the order of  
tens of microns



We demonstrated removal of relatively large amounts of material

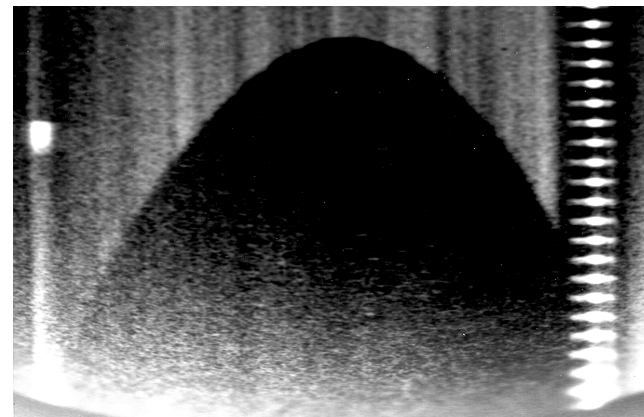


# Scientific Investigation

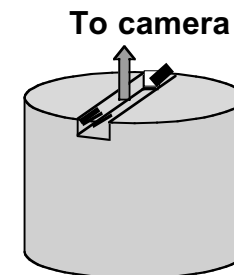


- Preparation of test specimens that are thinner than can be prepared by conventional machining.
- Drilling small holes for insertion of optical fiber diagnostics
- Machining steps and grooves in the surface of test specimens
- Machining small wedges of HE
- Machining contoured shapes
- Removing insulation from detonator cables for probe attachment

## Detonation velocity measurements

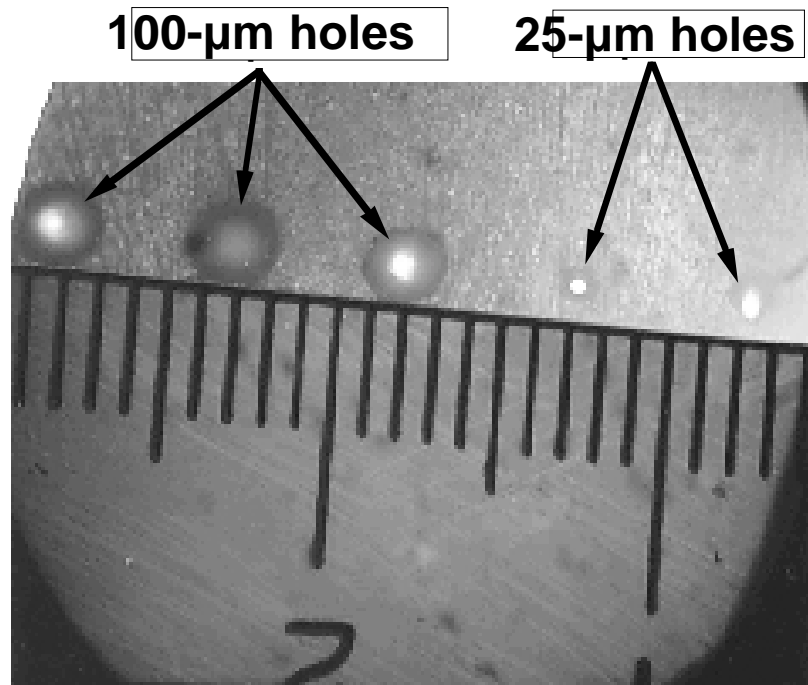


High-speed streak record of detonation breakout. Breakout time resolved to  $< 1\text{ns}$



## We laser drilled holes in 1-cm-thick explosives samples

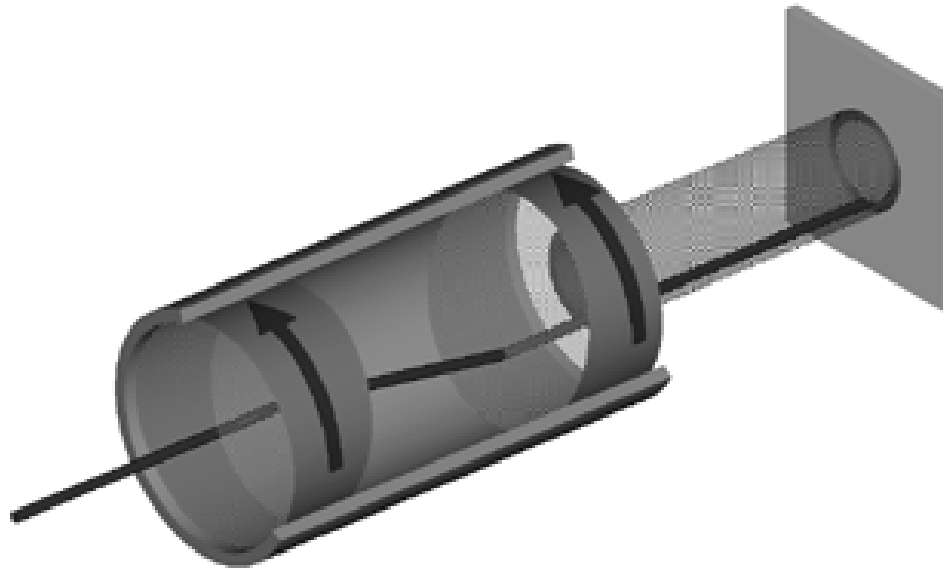
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- ¥ Non-trivial to drill small holes in explosives
- ¥ Useful for introducing wires and diagnostic probes in experiments

## Small tantalum disks were cut using optical trepanning technique

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¥ Previously the disks were formed by electronic discharge machining (EDM), a difficult And time-consuming process

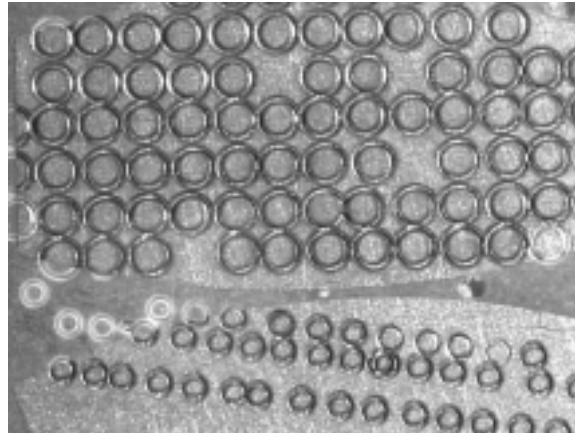
¥ Femtosecond laser machining of these disks proved to be 100 times faster and have fewer rejects

# Manufacture of Tantalum Disks

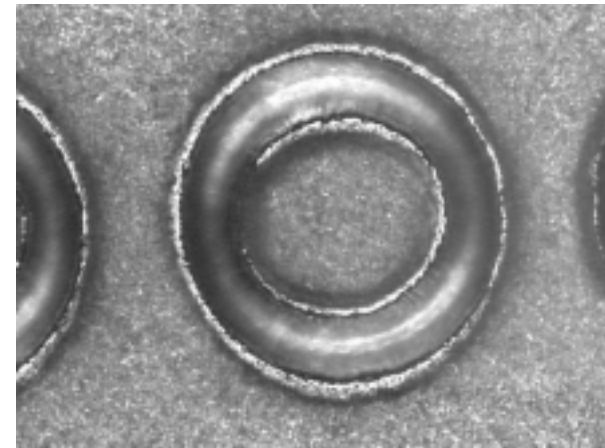
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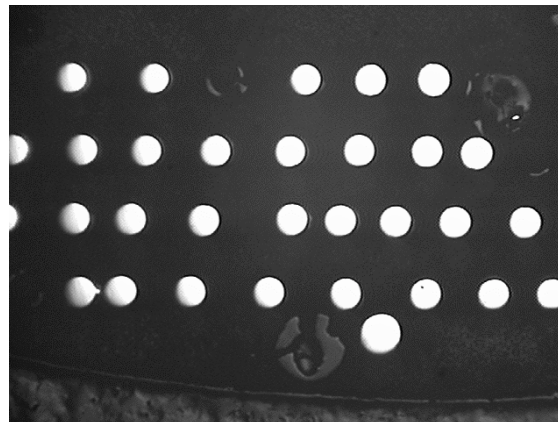
**Laser Trepanned  
circles cut in single-  
crystal tantalum.  
Small circles ~ 100  $\mu$ m  
diameter**



**Cut time 4 secs @ .1 watt ave.  
power. 50  $\mu$ m laser spot size  
and fluence of 2.9 J/cm<sup>2</sup>**



**Finished 100  $\mu$ m  
Diameter tantalum  
Disks after polishing to  
10  $\mu$ m thickness**



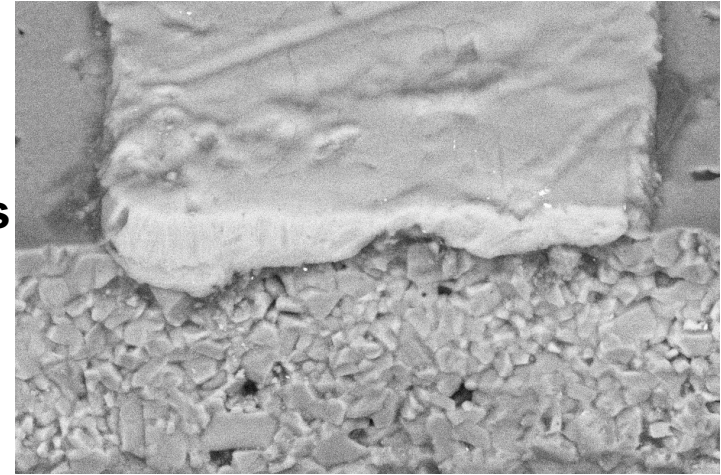
# Surveillance

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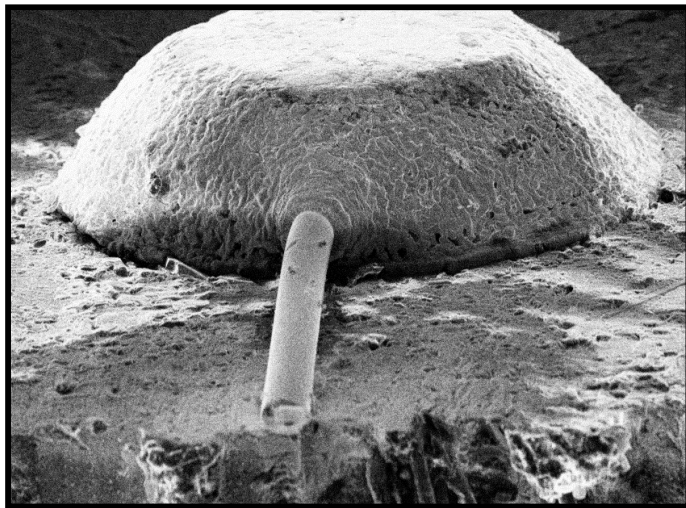


- Disassembly of energetic components
- Drilling access holes for gas sampling
- Cutting test specimens from larger charges
- Cutting cross-sections of components for inspection

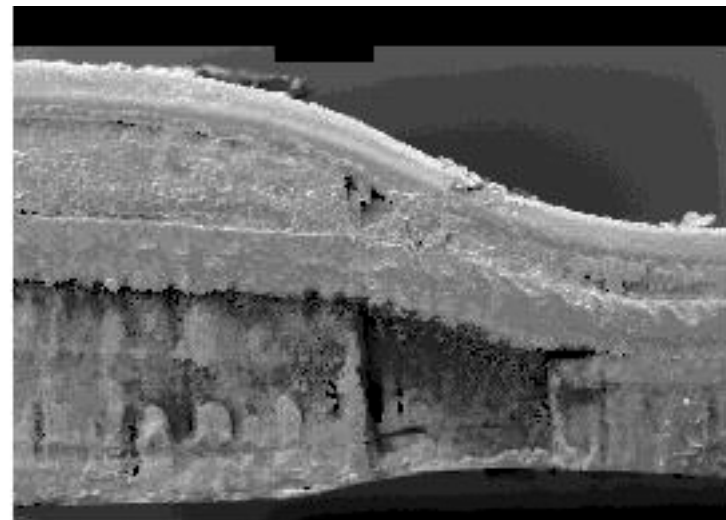
SEM of cut through a strip EBW header



SEM of cut EBW detonator header

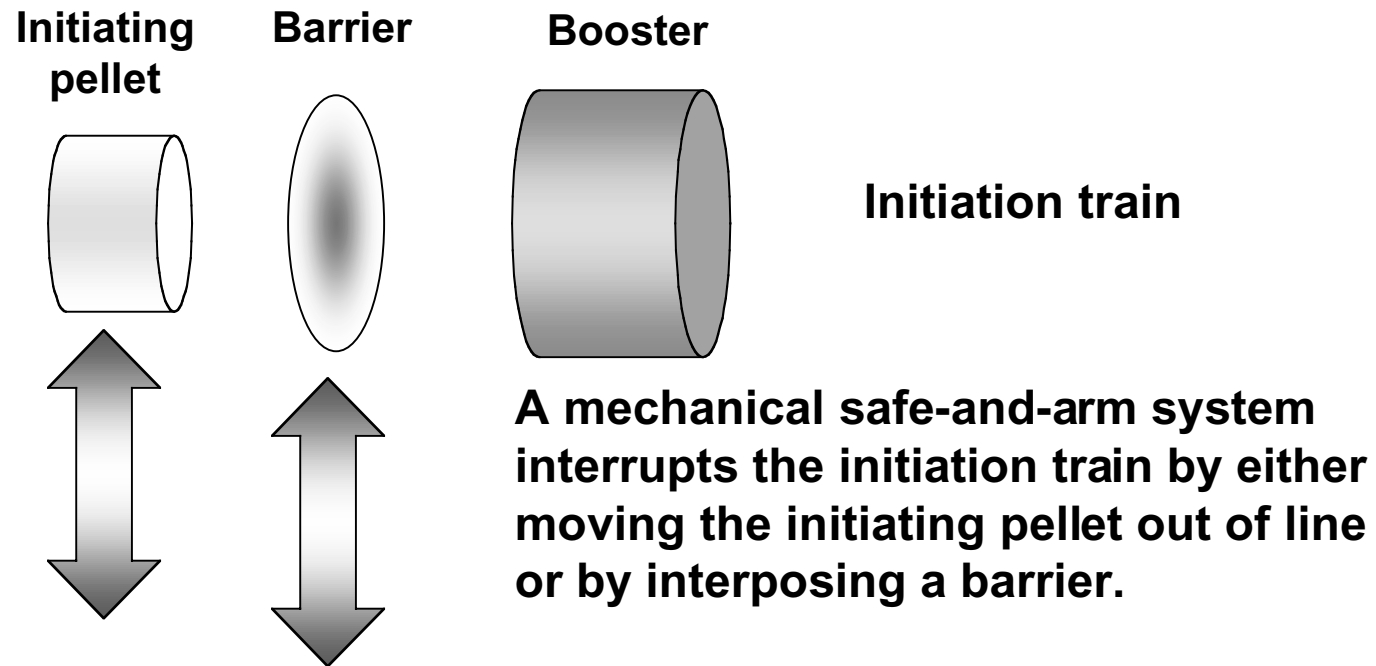


SEM of cut through flat cable



# Micromachined, safe-and-arm system

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**The DoD is very interested in micromachining tiny, mechanical, safe-and-arm systems for use in advanced munitions. In combination with other micromachining techniques, fs lasers have many possibilities for use in this area.**

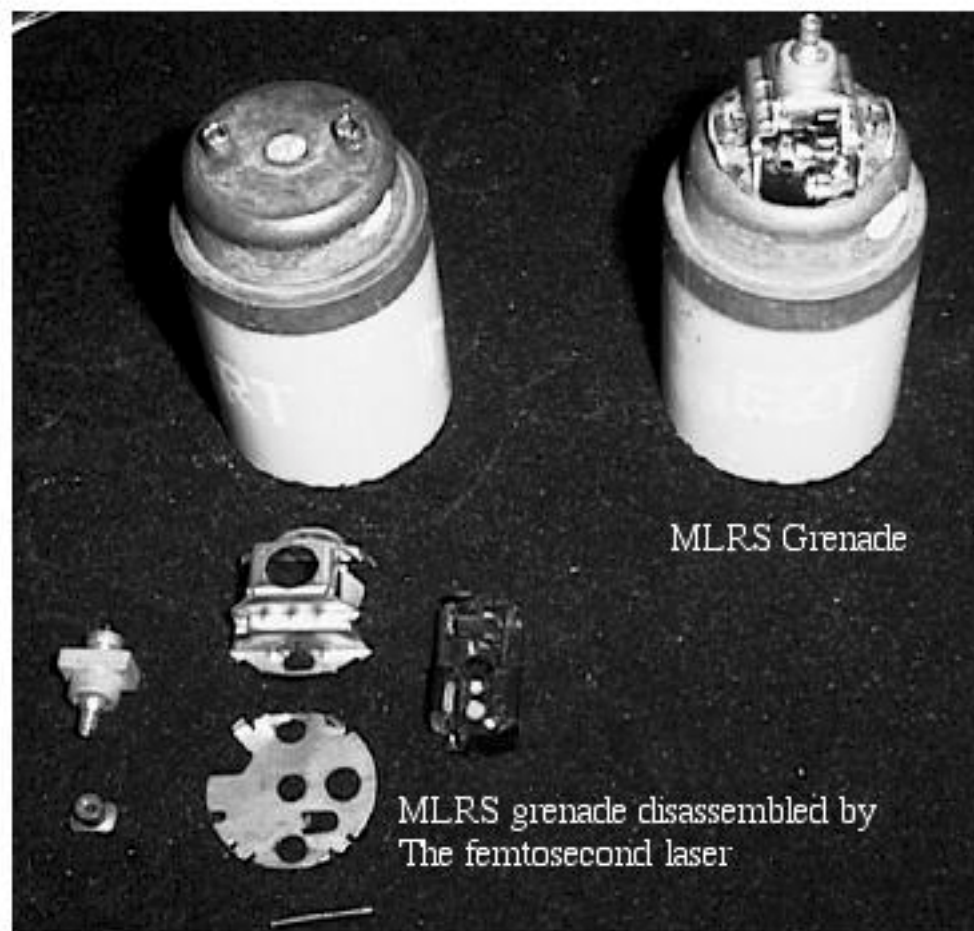
# Demilitarization

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The fs laser can function as a precision cutting tool for demilitarization.

- ¥ No heat transfer to sensitive materials
- ¥ Will cut both metals and HE without causing reaction
- ¥ Minimal waste generation
- ¥ Possibility of reusing high-value parts.

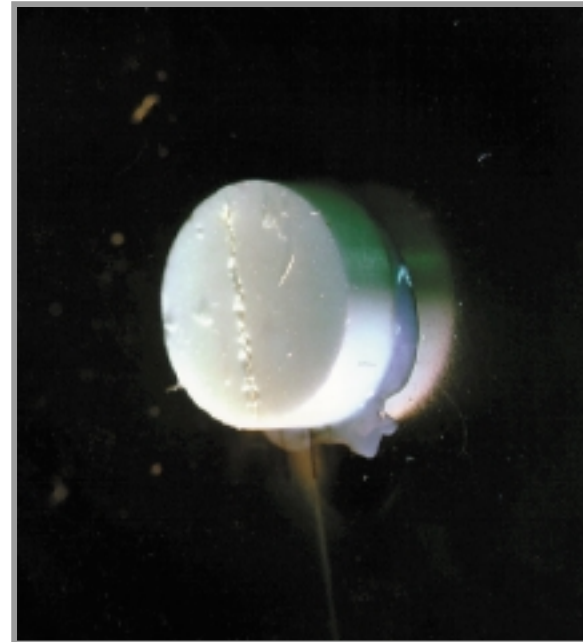


**In early experiments, we cut through HE and metals  
in both directions**

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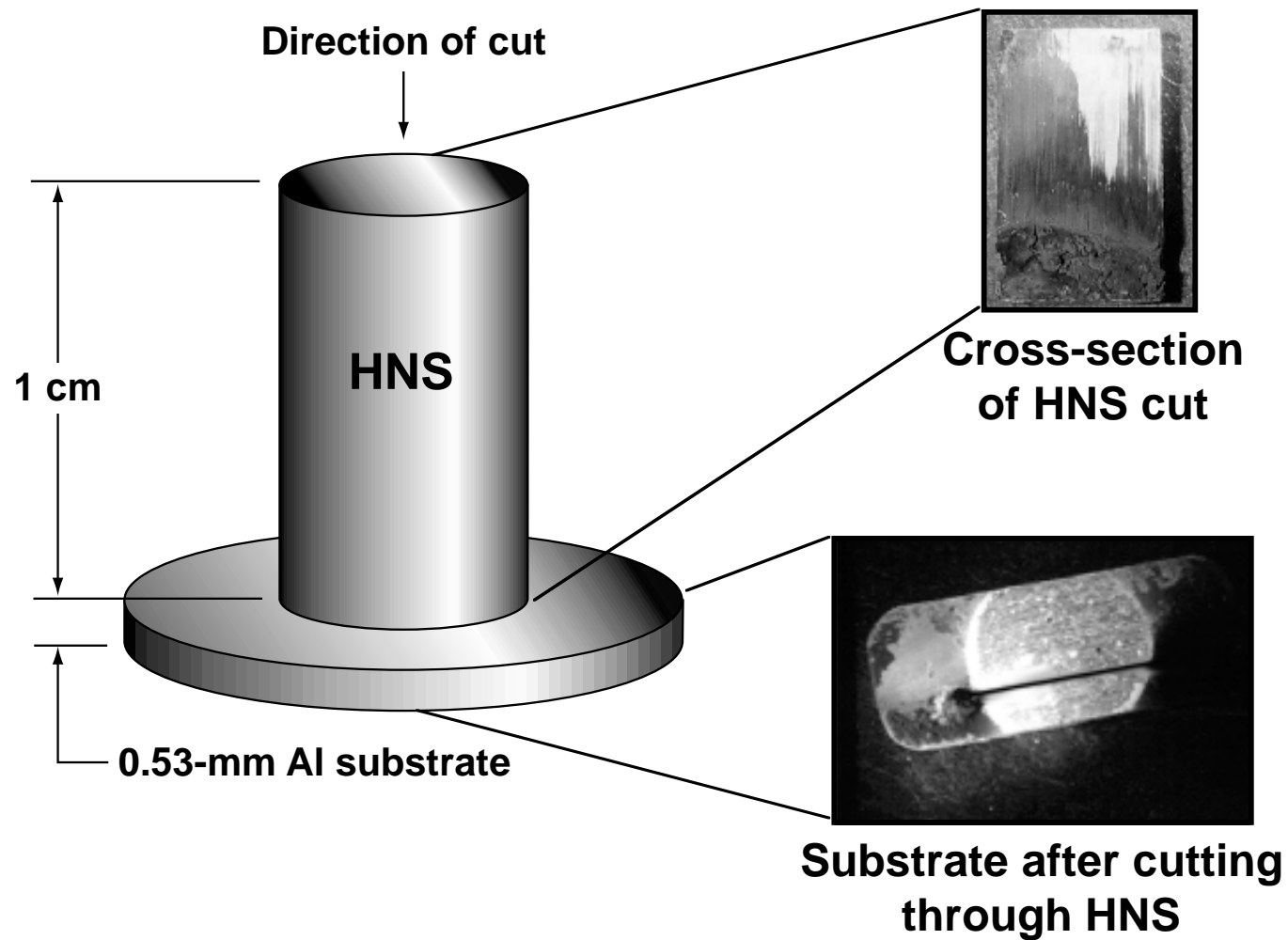
Cut through 1/2-mm steel substrate  
into HE sample (PETN)



That particular cut went through the 2-  
mm HE sample (from back surface of  
substrate)

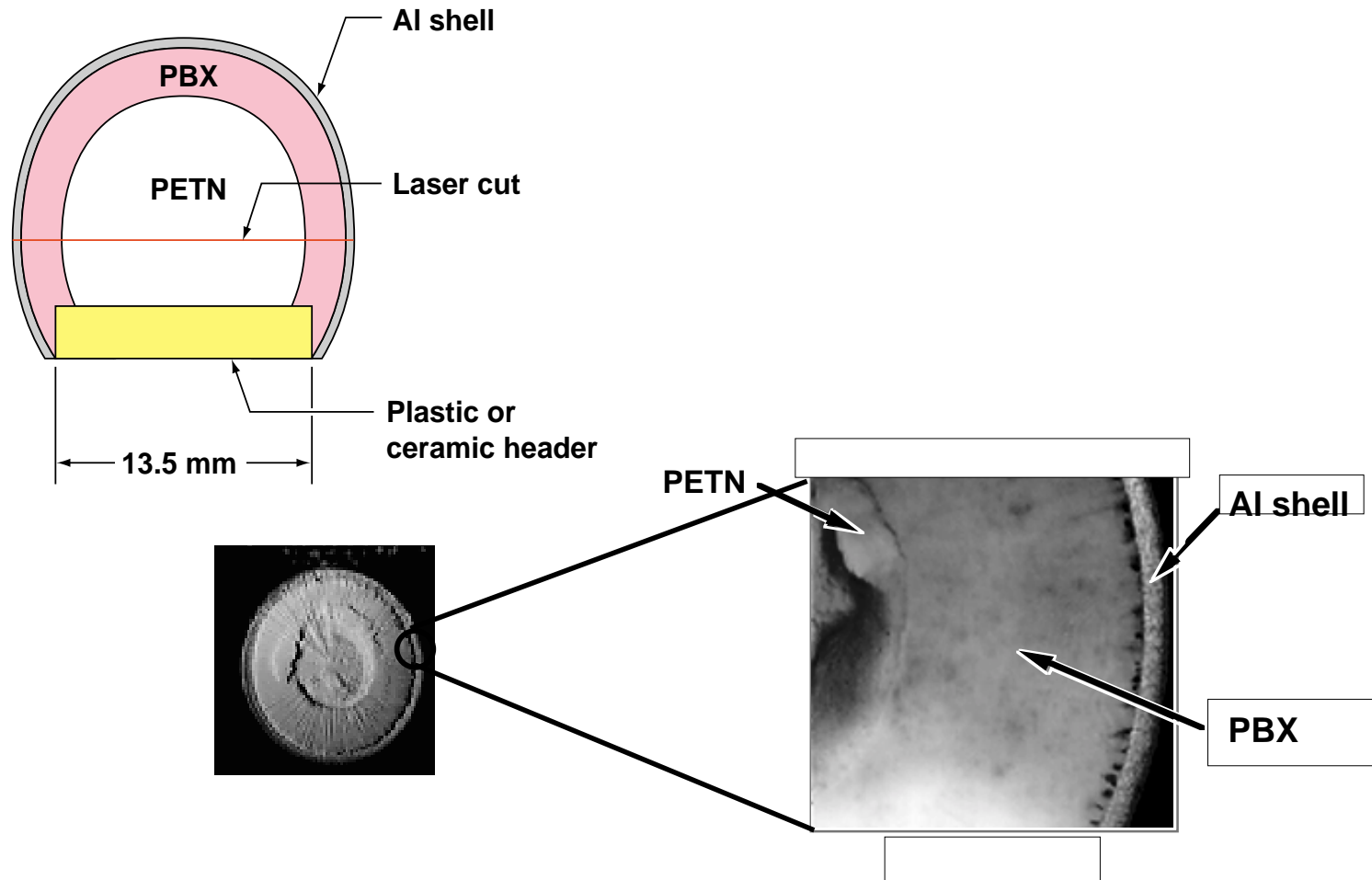
# In later experiments, we cut through thicker HE and more reactive metals

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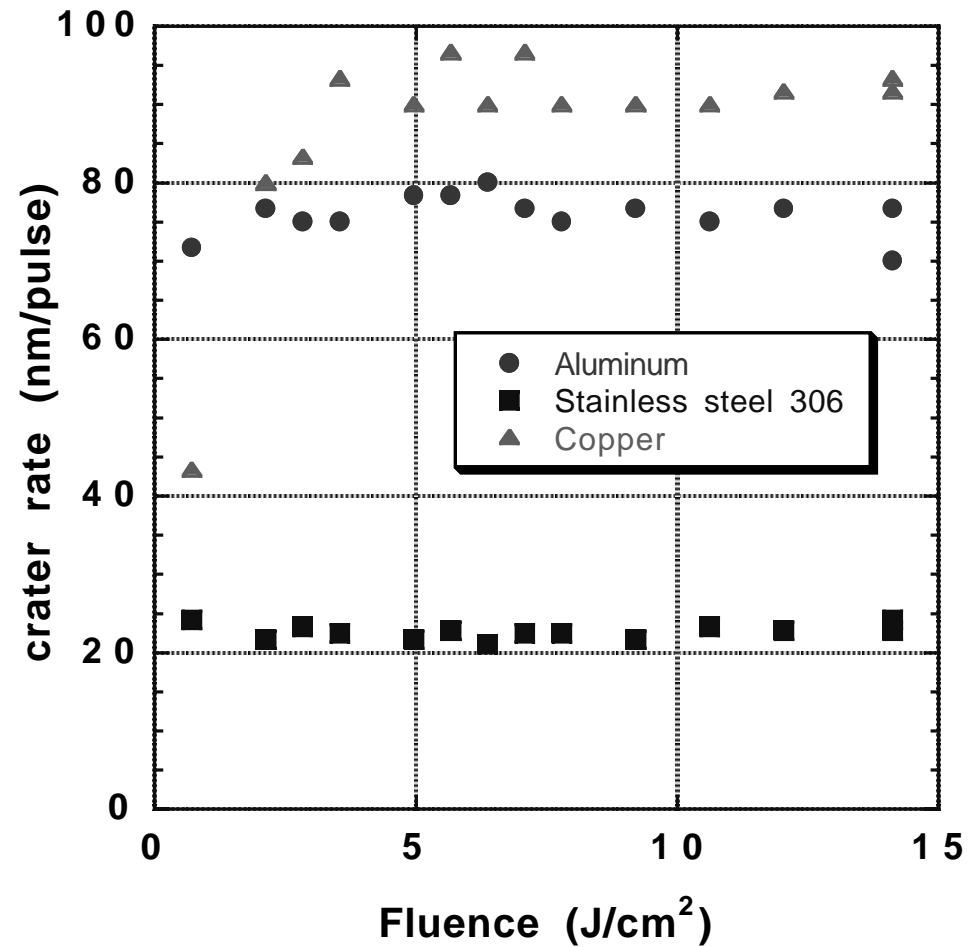


# We cut explosive components while preserving delicate internal structures

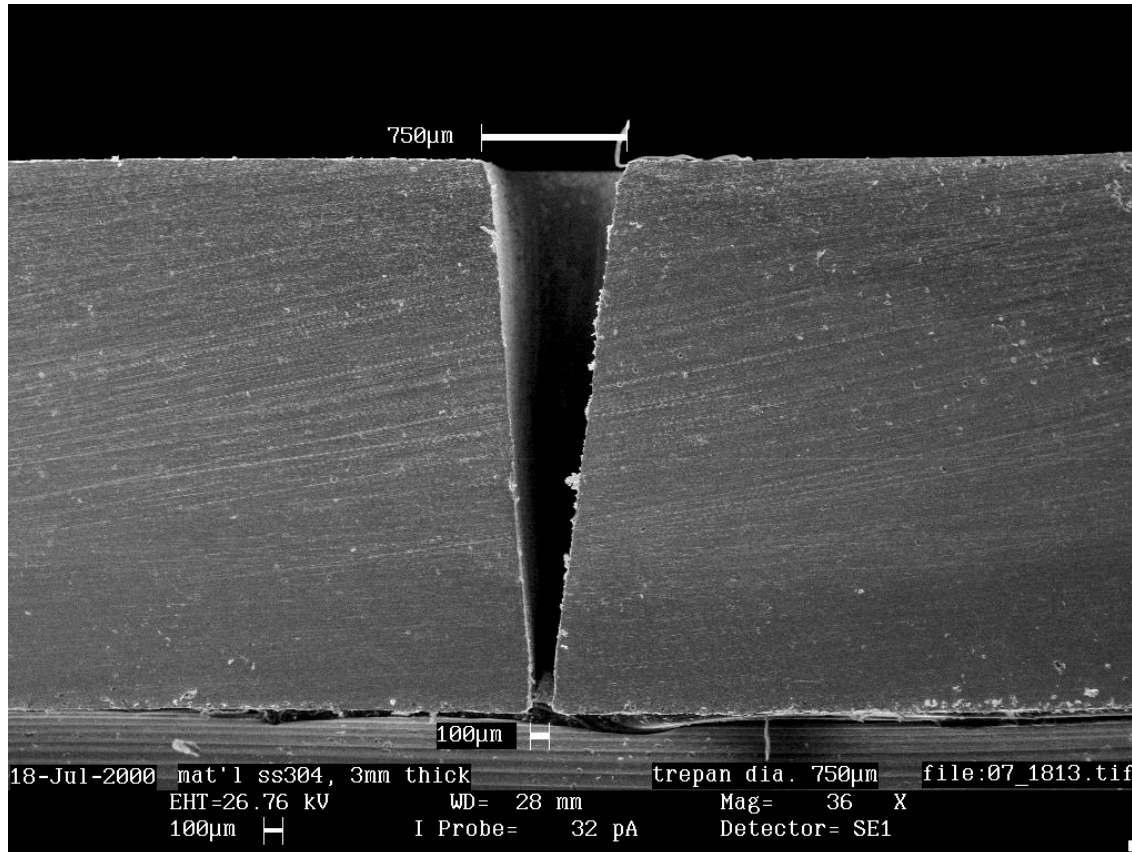
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## Material removal rates for shallow holes



# Femtosecond laser cut through 1/8 inch of Stainless Steel



- 1 cm long cut required 108 minutes
- Average laser power was 2 Watts
- Fluence was  $3.6 \text{ J/cm}^2$
- Cut was done in atmosphere
- Distance to target was 1-meter (1000mm)

# Programmatic applications for fs lasers

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¥ **Energetic materials processing**

¥ **Scientific investigation**

¥ **Surveillance**

¥ **Micromachining**

¥ **Demilitarization**

